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DSTO-TR-1064

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ABSTRACT

Military operations in tropical environments have imposed a significant challenge to the Australian Defence Force (ADF). The hot and humid conditions are known to cause debilitating effects on soldiers deployed to northern regions of Australia, with the consequence that the effectiveness and efficiency of operations were severely compromised. While the adverse effects of thermal stress on soldiers' physiological capability are well established, this has not been confirmed for cognitive performance. This impact of thermal strain on cognition has now been studied using psychometric testing and functional brain electrical activity imaging to investigate the impact of thermal stress on cognitive performance. The brain electrical activity of subjects was measured while undertaking a range of cognitive tasks. Steady State Probe Topography (SSPT), a novel brain imaging technology, was employed to monitor the changes in regional brain activity and neural processing speed of subjects under thermal stress. The psychometric test batteries, developed by the Brain Sciences Institute (BSI), were made up of the Rey auditory-verbal learning test, the inspection time, the digit span test the spatial working memory task and the AX-continuous performance task

The functional brain imaging provides topographical information, which shows changes of electrical activity in response to thermal stress during cognitive task performance. The changes in brain electrical activity and neural speed induced by thermal stress will help to identify the type of cognitive functions that are likely to be impaired.

Results indicated that subjects experienced increasing cardiovascular strain through thermally neutral to thermally straining conditions. The heat strain imposed on the subjects was substantial as indicated by the increase in their mean core temperature under thermally straining conditions. The psychometric test batteries, however, showed no significant performance decrements even under the most strenuous condition. Some deficits in working memory, in information retention and processing were noted but overall, behavioural changes that were reflective of the higher level of thermal strain were not observed.

In contrast, there were marked differences in the electrical responses of the brain when subjects were thermally strained. The Steady State Visual Evoked Potential (SSVEP) recordings showed an increase in amplitude and a decrease in latency, suggesting an increase in the utilisation of neural resources or effort by subjects to maintain the same level of performance under thermally neutral conditions. It appears that the brain imaging technology is potentially a valuable tool for examining the empirical relationships that complements and goes beyond conventional measures of behavioural responses.

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Executive Summary

The deployment of the Australian Defence Forces (ADF) to the northern part of the country has exposed soldiers to debilitating tropical environments. The impact of heat strain on physiological performance is well known. It will lead to physical exhaustion and ultimately death, if unchecked. If measures to avoid such outcomes are not taken, operational effectiveness and efficiency could be compromised. While heat strain can affect an individual's ability to accomplish specified tasks, its impact on cognition can complicate missions at a higher level. Command, control and communications may be impaired and the ability to analyse complex situations and make rational decisions can also be adversely affected. It is therefore important to understand the impact of thermal strain on cognition so that adequate management strategies can be developed to minimise such influences.

A psychophysiological evaluation of eleven subjects under three different conditions was conducted to examine the impact of thermal strain on cognition. These volunteers were tested under conditions which were thermally neutral (25°C and 60% rh, minimal exercise), thermally stressful (35°C and 60% rh, minimal exercise) and thermally straining (35°C and 60% rh, walking at speed of 5 $k.h^{-1}$ and a gradient of 5 to 8%). The brain electric activities were measured while subjects were performing specified tasks under the control (thermally neutral) and the experimental (thermally stressful and straining) conditions. The technique employed involved the use of a task-irrelevant stimulus (a 13 Hz visual flicker) to stimulate a subject while undertaking a cognitive task. The changes in amplitude and frequency of the steady state visual evoked potential (SSVEP) were then recorded and later integrated to allow for topographically mapping the electrical activities of the brain during task performance. This novel brain imaging technique, the Steady State Probe Topography (SSPT) was found to be superior in measurements of brain activity associated with rapid cognitive processing to other imaging modalities such as Positron Emission Tomography (PET) or functional-Magnetic Resonance Imaging (f-MRI). A series of psychometric test batteries was either used in conjunction with the SSPT or as a stand-alone package to delineate performance changes as a result of the changes in environmental conditions.

Results indicated that subjects experienced increasing cardiovascular strain through thermally neutral to thermally straining conditions. The heat strain imposed on the subjects was substantial as indicated by the increase in their mean core temperature under thermally straining conditions. The psychometric test batteries, however, showed no significant performance decrements even under the most strenuous condition. Some deficits in working memory, in information retention and processing were noted but overall, behavioural changes that are reflective of the higher level of thermal strain were not observed.

In contrast, there were marked differences in the electrical responses of the brain when subjects were thermally strained. The SSVEP recordings showed an increase in amplitude and a decrease in latency, suggesting an increase in the utilisation of neural resources or effort by subjects to maintain the same level of performance under thermally neutral conditions. These findings are consistent with a theory which suggests the existence of a 'cognitive reserve'. Subjects will draw on the reserve to maintain performance under more stressful conditions. When the reserve is depleted or overloaded, behavioural changes and performance deterioration will then occur.

While the conventional psychometric test batteries give a broad indication of performance decrements when one is challenged with a higher level of thermal stress, the SSPT technique has demonstrated its high sensitivity and applicability in detecting and amplifying the subtle differences in brain electrical activities that are reflective of the changes of the stress level. In this regard, this brain imaging technology is potentially a valuable tool for examining the empirical relationships that complements and goes beyond conventional measures of behavioural responses.

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Chris Hocking graduated from Swinburne University of Technology (SUT) with a co-major in Psychology and Psychophysiology in 1993, continuing at SUT with a course for Master of Applied Science in Cognitive Neuroscience. He investigated the processes of automatisation, human-machine and human-process interface. Specifically his research addressed the changes in behaviour and brain activity associated with automatisation of a simple arithmetic task. His current interests lie in the field of learning and the development of skill, including the conditions required to acquiring skill and expertise and its transfer within individuals. He has recently passed his thesis examination and is expected to be awarded with a M,Appl.Sc. Degree.

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Richard Silberstein graduated from Monash University with a B.Sc in 1968 and from Melbourne University with a Ph.D. in 1974. He is currently the Professor and Director of the Brain Sciences Institute, Swinburne University of Technology. He is also an Adjunct Professor in Biomechanical Engineering, Tulane University, New Orleans, USA and a member of the Editorial Board of the Journal of Brain Topography. He also holds the position of Chairman, Executive Committee, Pan Pacific Conference on Brain Electric and Magnetic Activity and member of a number of learnt societies in neuroscience, psychophysiology and engineering in medicine. He has over 100 publications in various peer-review journals.

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Tony Wai Man Lau graduated with a B.Sc (Hons) from the Chinese University of Hong Kong (CUHK), Hong Kong in 1979 majoring in Biology and Biochemistry. He obtained his M. Phil degree in environmental toxicology from the same University in 1981. Supported by a Croucher Foundation Scholarship (HK), he studied environmental toxicology at Melbourne University and was awarded a Ph.D. degree in 1987. After a short spell of employment with the Unipath Pathology Laboratory, he joined the then Materials Research Laboratory (MRL) in 1985 and conducted pharmacological studies leading to improved prophylaxis and therapy of nerve agents. He is currently a Senior Research Scientist managing a task in combatant performance. He was a member of a Human Science Review Team and is now the Australian National Leader and Chairman of TTCP HUM TP 6. He is also the Area Focus Leader (Environmental Physiology and Nutrition Group) of the Human Factors Hub of DSTO.

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Warren Roberts graduated from Swinburne University of Technology (AUS) with a B.App.Sci. in Medical Biophysics and Instrumentation in 1993. He then obtained his Grad. Dip. in Social Statistics in 1997 and has recently be awarded with a M.Appl.Sci. in Haemorheology in 1999. During both undergraduate and post-graduate studies he was associated with the Australian Institute of Sport in Canberra, working as an assistant researcher on the physiological and biochemical assessment of elite athletes. He is currently a member of the Combatant Performance task providing scientific support and participating in laboratory and field trials as a Professional Officer (Grade 2).

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Con Stough graduated with a PhD from the University of Adelaide in 1995. His doctoral research focussed on biological measurement of intelligence and personality. He has also completed post doctoral work in cognitive psychophysiology at the Universities of Auckland in New Zealand and Queensland in Australia. His main area of research focusses on understanding the neural and pharmacological basis of intelligence and cognition, with relevance to the cholinergic neurotransmitter system and neuropsychology and cognition. He is particularly interested in examining nootropic agents and in identifying the neural and/or genetic basis for intelligence. He is currently an Associate Professor in Cognitive Neuroscience at Swinburne University of Technology .

Contents

1. Introduction

A wide range of environmental factors can influence human performance. Of these, high heat and humidity are particularly debilitating, as elevated environmental heat could impose an enormous strain on the cardiovascular system to maintain a consistent body temperature. Failure to dissipate excessive body heat will lead to a rise in deep core temperature, resulting in physiological dysfunction, heat exhaustion and, if unchecked, death. While the physiological responses to environmental heat have been well established, it is less clear about its impact on cognition.

Hancock (1986) conducted a review on the effects of thermal environments on vigilance. It was concluded that thermal stress would not cause deterioration unless external conditions are severe enough to perturb the deep core temperature. It is interesting to note that subjects in a state of static hyperthermia actually performed better on tasks that required sustained attention. The improvement could be related to a general physiological arousal due to an activation of the thermoregulatory mechanisms (Teicher, 1966).

Bunnell and Horvath (1989) studied the interactive effects of heat, physical work and carbon monoxide (CO) exposure on cognitive task performance under conditions of 30°C Wet Bulb Globe Temperature (WBGT) and found no evidence of cognitive impairments, except when blood CO level was elevated. Sharma et al (1986) artificially induced dehydration on subjects by exercising them in dry/hot and humid/hot conditions, and studied their mental functions when hypohydration of up to 3% reduction of body weight was achieved. Results indicated that a significant reduction in mental efficiency was observed when primary dehydration was at 2% or above. Razmjou (1996) argued that a deficit in mental performance in the heat could be offset by an increase in arousal, particularly when task demand is low. His studies showed that under conditions of slight hyperthermia, demand on the information-processing system was little changed when a cognitive task was performed. Indeed, performance of a simple (primary) task in the heat was improved, presumably due to an increased level of attention. Only tasks of a more complicated nature (secondary task) resulted in a significant performance deficit. There appears to be a general consensus that thermal strain will compromise cognition, but the level of performance deterioration is dependent on the severity of heat strain and the complexity of task.

While conventional psychometric test batteries can provide a broad understanding of cognitive performance under specific conditions, recent advances in brain-imaging techniques have increased the capabilities for visualising the working brain. These techniques are potent tools to uncover the functional areas of the brain responsible for various cognitive tasks, leading to a better understanding of the neural architecture of mental abilities (Sergent, 1994).

In hot and humid conditions, the cognitive functions most vulnerable are probably the maintenance of vigilance and short-term working memory (Johnson and Kobrick, 1998). Silberstein et al (1990) have developed special EEG paradigms known as Steady State Probe Topography (SSPT) which can delineate the spatial and temporal relationships of brain electrical activities during cognitive task performance. This modified probe evoked potential methodology will provide a more definitive assessment of neural dynamics and brain functional hierarchy associated with sustained attention under thermal strain.

In a military context, it is important to understand the limitations of human performance imposed by environmental heat as so many strategically important areas lie in hot regions (Johnson and Kobrick, 1998). Australia's Strategic Policy (1997) indicated that the focus of future military operations would be in the north. This means that soldiers would have to operate in tropical conditions, and the likelihood of heat illness, if unprepared, would be high. While physiological deterioration can certainly physically affect an individual in accomplishing specified tasks, the inability to assess situations and make rational decisions due to cognitive deficit could have profound effects that may compromise the mission at a higher level. Communications, command and control may break down, and adversely affected mission accomplishment. It is therefore imperative to develop an appropriate methodology for assessments of cognitive performance in the heat so that strategies for thermal stress management can be improved.

This study aims to use psychometric testing and functional brain electrical activity imaging to investigate the impact of thermal strain on cognition. The SSPT technique is employed to investigate regional changes of brain activity and information processing speed while subjects perform specific tasks under thermal stress. The psychometric testing can be used as a stand- alone package for assessing cognitive performance or to complement the outcomes of the SSPT measurements.

2. Scope of Study

This was an experimentally based study involving measurement of physiological indicators of thermal strain, as well as electrophysiological and behavioural measures of cognitive functioning. The study was primarily exploratory, given that the approach used to measure brain function under conditions of thermal stress/strain was relatively novel. The study had the following objectives:

- To develop brain electrical activity imaging techniques and to quantify cognitive performance in thermally stressful environments.
- To develop a highly sensitive psychometric test battery for measuring cognition in thermally stressful environments.

- To quantify the effects of thermal strain on cognition using both the brain wave imaging techniques and psychometric test battery.

3. List of Project Stages and Activities Undertaken

Research project commenced in September 1998.

Stage 1 - Planning of cognitive activation tasks, software development and modification of activation tasks (September-October 1998, 4-6 weeks, BSI)

Stage 2 - Evaluation of recording problems in conditions of high heat and humidity (October-December 1998, 4 weeks, BSI)

Stage 3 - Pilot evaluation of experimental protocol. Modification of protocol if necessary (January-February 1999, 4 weeks, BSI)

Stage 4 - Psychometric testing and SSPT recordings in unstressed environment (February 1999, 4-8 weeks, BSI)

Stage 5 - Major trial involving psychometric and SSPT recording in conditions of thermal stress (March-June 1999, AMRL Maribyrnong)

Stage 6 - Analysis of experimental data and completion of report (July-September 1999, BSI)

4. Development of Methodology

4.1 Brain Imaging Approach

Brain electrical activity was recorded using a technique developed at the Brain Sciences Institute (BSI) termed Steady-State Probe Topography. It utilises the steady-state visual evoked potential (SSVEP) which involves the use of a probe or task-irrelevant stimulus (a visual flicker), follows by observing the changes in amplitude and phase of the potential evoked by that probe stimulus when a cognitive task is undertaken (Silberstein et al., 1990).

The Steady-State Probe Topography is a powerful technique for the measurement of brain activity associated with rapid cognitive processing. While other imaging modalities (i.e., PET, fMRI) offer high spatial resolution, the low temporal resolution

(from about one minute upwards) does not allow a distinction between uniform or transient activation within that minimum time-frame (Silberstein et al., 1995). On the other hand, the Steady-State Probe Topography technique provides a measure of rapidly changing brain processes in a continuous fashion and with a relatively high temporal resolution (seconds) (Silberstein et al., 1990). Such high temporal resolution also allows the cognitive components of each trial of a task to be separated from the perceptual and motor components of that trial. As such, the Steady-State Probe Topography technique is sensitive to continuous and rapid changes in brain activity.

4.2 Recording Difficulties

Recording under conditions of increased temperature and humidity creates unique problems for recording of EEG. Such environmental conditions are not conducive to easy use of electronic equipment, because of the dual possibilities of overheating and formation of condensation on hardware components. Indeed, a number of times during recording sessions, overheating caused malfunction of the treadmill and the computer used for displaying the SSPT activation tasks. Condensation was only a problem when shifting hardware from different environments, such as the first time the equipment was brought from outside into the hotter and more humid conditions of the Environmental Chamber.

A further problem of recording in this environment arises from the increased sweating that subjects experience, which causes 'bridges' of sweat to electrically connect scalp electrodes, which under normal EEG recording conditions, are supposed to be directly electrically insulated from each other (except via the scalp). Non-scalp pathway connections between electrodes have the effect of reducing the spatial resolution of the EEG, effectively creating one large electrode rather that a cluster of separate electrodes. The problem with sweating is that it may be non-uniform across the scalp, leaving some electrodes to perform as expected whilst others are "bridged", leading to differences in the EEG signal due to recording conditions rather than due to differing regional brain activity. To overcome the possibility of inconsistent connections between electrodes, it was decided to use the electrically conductive EEG gel to "sweat for the subject". This would have the effect of removing sweat-induced variations in inter-electrode resistance, and was accomplished by applying a low-conductive gel to the entire head.

Another aspect of this study, which created a difficulty in recording EEG, was the fact that to maintain subjects' temperature at or above 38.5°C, the subjects had to continue exerting themselves during the recording period. The consequences of this were two-fold: 1) treadmill operation created an electrically "noisy" environment and 2) movement of the subjects produces large voltage, undesirable signals (artifacts) that mask the extremely low voltage, underlying cortical activity of the brain. This is an atypical condition under which to record EEG, and far from the ideal situation.

The first difficulty was partially overcome by removing the electronic 'noise' (50 Hz interference) using a filter that cut off any frequencies higher than 40Hz. Additionally, use of the Steady-State Probe Topography technique enabled further reduction of electrical interference, since one of the properties of the technique is the ability to filter out unwanted electrical signals. With regard to the second difficulty, perhaps the biggest problem caused by movement is "clipping", a situation whereby the electrical signal exceeds the dynamic range of the amplifier. In such a situation, all information conveyed by the EEG signal is lost, and to minimise this possibility an amplifier with a large dynamic range (16-bit) was utilised. The speed and magnitude of movement is directly associated with the amount of artifact produced, and so the speed of the treadmill during recording was held at 1.8 $km.hr^{-1}$ to reduce the production of artifact as much as possible.

5. Method

5.1 Subjects

Due to difficulties in obtaining soldiers to volunteer for this study, staff members from DSTO Maribyrnong were recruited as subjects. There were eleven males, with an average age of 31. Some basic physical characteristics of these subjects are listed in Table 1.

Table 1: Physical characteristics of the subjects

Subject	Age	Weight (kg)	Height (m)
S1	26	98.7	1.92
S2	45	75.5	1.78
S3	32	71.0	1.70
S4	32	91.4	1.67
S5	29	81.4	1.80
S6	32	81.9	1.71
S7	20	74.1	1.82
S8	33	72.6	1.70
S9	38	72.6	1.73
S10	35	76.6	1.79
S11	27	85.4	1.81
Mean±SD	31.7±6.5	80.1±8.8	1.77±0.07

5.2 Experimental Design

The study was designed to examine the effects of thermal strain on cognition under the following three levels of thermal stress: 25°C/65%RH, 35°C/65%RH, and 35°C/65%RH with raised core temperature ≥38.5°C).

Before the commencement of the trial, subjects participated in an acclimation program by walking on a treadmill at 5% gradient and 5 km.hr^{-1} for 60 minutes on three separate days. The acclimation program for each individual finished within one week and none of the subjects had to wait for more than one week after the acclimation before the trial commenced. During the acclimation, subjects were trained to be familiarised with the psychometric tasks that were later used in the trials. Practice sessions were again made available before each psychometric testing, thus minimising the potential effects of learning. To ensure that fatigue due to physical exercise had minimal impact on the subjects, only one set of thermal conditions was tested on a single day. In addition, the psychometric and cognitive test battery was administered to all subjects in the same sequence for all trials. This ensured that the impact of fatigue imposed was similar in each test condition, making the environmental conditions the dominating factor influencing the performance. There was a gap of at least two days before each subject returned for the next test. Due to the difficulty in switching the temperature and relative humidity of the environmental chamber between the required conditions during the normal working hours of a day, the order of the test was only partially counterbalanced. Five volunteers had their test conducted in the thermally strenuous condition (35°C/65%RH plus exercise) with raised core temperature before the thermally stressful condition (35°C/65%RH, no exercise), while one subject was tested under the thermally neutral condition (25°C/65%RH, no exercise) after tests in the other two conditions were completed.

During the third condition, core temperature was raised by making subjects walk at 5 km.hr^{-1} on an incline of 8-12% for a period of about forty minutes. Subjects then continued to walk on the treadmill at a slower pace (1.8 km.hr^{-1}) to sustain increased core body temperature during the recording session. To maintain consistency across conditions, subjects also walked on the treadmill at 1.8 km.hr^{-1} for the 25°C and 35°C conditions during recording.

5.3 Procedure

Subjects donned their army uniform, the Disruptive Pattern Combat Uniform (DPCU) before instrumentation. This involved attachment of a Polar heart rate monitor, followed by placement of the rectal thermistor (self-administered after instruction) for the purpose of measuring core temperature. For the raised core temperature condition (35°C +NBC), subjects wore, in addition to the DPCU, a Nuclear Biological and Chemical protective suit (NBC Mk IV) currently issued to the ADF.

Preparation of reference and ground electrode sites was then carried out, followed by application of the electrically conductive gel to the scalp. This was rubbed into the hair and scalp by each subject before the electrode cap was placed on the head.

EEG was recorded from subjects using standard electrophysiological techniques, with the nose serving as ground and linked references attached to each earlobe. Brain electrical activity was amplified and bandpass filtered, prior to digitisation to 16-bit accuracy at a rate of 500Hz, and stored for later off-line analysis.

Subjects then stepped on to the stationary treadmill and each electrode was checked to ensure a steady signal. For the 25°C and 35°C conditions, the treadmill was then started and subjects walked at a slow pace (1.8 $km.hr^{-1}$), which was maintained during the recording session. For the 35°C +NBC condition, subjects began walking at a higher speed (5 $km.hr^{-1}$) and on an incline of 8-12% in order to raise their core temperature. The work rate was individualised and was maintained (under supervision by regularly observing the heart rate and subjective ratings of well-being) until their core temperature reached 38.5°C. The treadmill was then set to 0% gradient and the speed to 1.8 $km.hr^{-1}$, in preparation for the beginning of the recording session and the conduct of the psychometric tests. Each individual test took no more than 10 minutes to complete and the entire procedure lasted approximately 30 to 35 minutes.

5.3.1 Administration Order of Psychometric and SSPT Activation Tasks

The SSPT activation tasks (*) are part of the entire psychometric testing battery. Selection of these tests in conjunction with EEG recording allowed for investigation into specific events in time related to the processing of information. The events were 'marked' by the computer and the recorded epochs were averaged between and within subjects. The other tasks were conducted without concurrent EEG recording because they did not allow task administration or behavioural responses to be synchronised with the EEG. Moreover they required verbal responses and muscle activity associated with speech which may have obscured the electrophysiological signals of interest.

Rey Auditory Verbal Learning Test (Trials 1-7) (7 minutes)
Spatial Working Memory* (4 minutes)
Spatial Working Memory Control Task* (4 minutes)
AX-Continuous Performance Task* (4 minutes)
Reference Task* (4 minutes)
Digit Span* (3 minutes)
Rey Auditory Verbal Learning Test (Trial 8 + Recognition) (2 minutes)
Inspection Time (off treadmill) (5 minutes)

(See Appendix A for descriptions and explanations of both the psychometric and SSPT activation tasks, all times are estimated only)

5.3.2 Electroencephalographic Recording

The electrode cap was a commercially available from Surgicon Systems Pty. Ltd, USA. The 64 electrodes utilised all of the electrode positions defined by the International 10-20 system, as well as additional sites located between those positions (Figure 1). There was an average inter-electrode separation of 3.2cm (Silberstein et al., 1990).

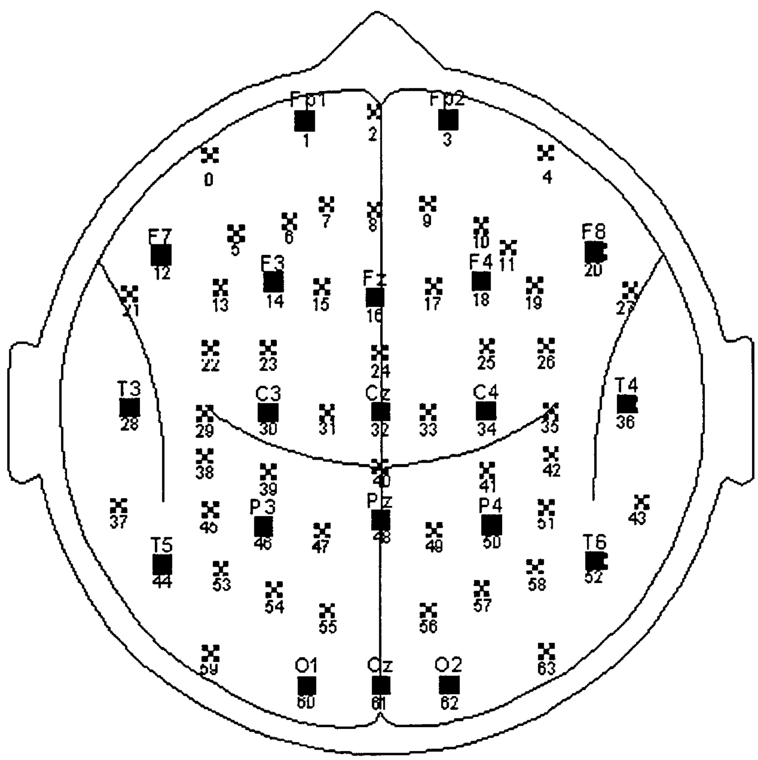


Figure 1: *Position of all 64 electrodes in helmet. This is a view from above the head, with the nose at the top and ears at the side. Black squares indicate International 10-20 System positions. Crosses indicate the 44 additional sites. The Rolandic and Sylvian sulci are marked by the transverse and lateral curved lines respectively.*

5.3.3 SSVEP Stimulus

The stimulus used to evoke the SSVEP consisted of a 13Hz sinusoidal flicker subtending a vertical angle of 90° and a horizontal angle of 160°. The modulation depth of the stimuli when viewed against the monitor background was 45%. A set of half-silvered goggles which sat in front of the subject's eyes allowed the sinusoidal flicker to

be superimposed upon the subject's viewing field and hence, the task stimuli (Figure 2). These goggles were positioned in front of the subject's eyes prior to recording.

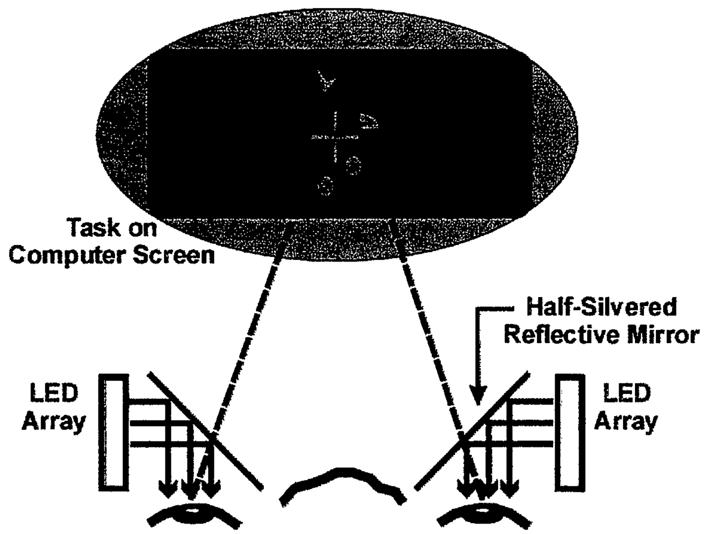


Figure 2: *Superimposition of SSVEP eliciting flicker on visual field. The half-silvered goggles reflected the flicker stimulus into the eyes of the subject, but at the same time, also allowed the subject to view the task on the computer monitor. Two arrays of light emitting diodes (LED's) were the source of the 13Hz visual flicker, and because they were red in colour, gave a red tinge to the subject's visual field.*

5.4 Data Analysis

5.4.1 Signal Processing

The electrophysiological response to the sinusoidal steady-state visual flicker stimulus was smoothed using a "running average" procedure. An epoch of a given length was selected to serve as an integration or 'averaging window' from which the amplitude and phase responses of the SSVEP were determined from its 13Hz Fourier cosine and sine coefficients. In this study, the epoch length chosen was twenty cycles of the stimulus waveform. The twenty cycle averaging period was then shifted one stimulus cycle along and the coefficients were recalculated for this overlapping period. This process was performed for data recorded from each of the 64 electrodes and repeated until all the data (approximately 300 secs for each task) had been analysed.

The choice of length of the integration period was a compromise between temporal resolution and noise rejection. A smaller window width increases temporal resolution of the data but decreases the signal to noise ratio, whereas increasing the width has the

opposite effects. (Silberstein et al, 1990). The twenty cycle integration period chosen yielded a temporal resolution of 760 ms, which gave adequate rejection of irrelevant EEG components whilst allowing observation of rapid changes in SSVEP amplitude and phase associated with cognitive processing.

5.4.2 Normalisation

It was necessary to "normalise" each subject's data prior to group averaging to prevent skewing. This was achieved by calculating the average SSVEP amplitude across the reference task for each electrode. The mean of these sixty-four values (one for each electrode) was calculated and all data was divided by this mean figure to give a value close to one (1) for all subjects. This minimised differences between subjects while retaining relative differences in the SSVEP within each subject.

5.4.3 Artifact Detection

The SSPT is relatively insensitive to noise and artifacts such as EMG and EOG because such artifacts have their power spread over a wide range of frequencies whilst the power of the stimulus frequency is focused at 13Hz or its harmonics (Silberstein et al, 1990). Nevertheless, an artifact detection process was used to identify electrodes which showed excessive clipping or whose mean amplitude and phase data deviated significantly from its four nearest neighbours. Such electrodes were excluded from further analysis and their data replaced by a weighted mean from acceptable adjacent electrodes, which due to the relatively close spacing of the 64-channel system were expected to be highly correlated with their neighbours (Nunez, 1981).

5.4.4 Averaging of Task Events

Each trial within the four SSPT activation tasks consisted common events whose time of occurrence was logged by computer. For the Continuous Performance task, these events were the presentations of the letters on the screen, and for the Spatial Working Memory task, they were the presentation of the target shapes, the mask, the retention interval and the presentation of the probe shape. During analysis, these parameters were used to select epochs of SSVEP data associated with specific events - for example, the SSVEP data associated with the presentation of the target shapes in the Working Memory task, or the 'A' and 'X' in the Continuous Performance task.

Epochs of data were selected that were centred about an event of interest in each trial in each task. For the Working Memory task, this was the time of presentation of the mask which followed the target shapes. The mask preceded the retention interval or "holding" period, when the spatial location of the target shapes had to be maintained in memory. For the Continuous Performance task, the event of interest was the presentation of the 'X'. Events were chosen so that the activity immediately following presentation and relating to processing of the target shapes and 'X' could be investigated. The length of epoch was 10 seconds to allow for observation of changes in

the SSVEP for 5 seconds before and 5 seconds after presentation of the sequence. This followed from our interest in the changes in the SSVEP during the 3 second retention interval following the mask for the Spatial Working Memory task, and to search for the presentation of the 'A' in the Continuous Performance task, which occurred 2.2 seconds before the 'X'.

For each subject, the epoch of data was extracted and pooled with other such epochs, and then averaged. This process was repeated for each electrode. Once a mean amplitude and phase value for each electrode within each subject had been calculated, the data for subjects was pooled and averaged again to give a cross-subject average of the SSVEP amplitude and phase associated with task performance.

5.4.5 Statistical Analysis

Statistical analysis of behavioural data (response time and accuracy) consisted of repeated measures of ANOVA's for examining the differences in task performance across the three thermal stress conditions. The comparisons made in the SSPT analysis were between the control and 35°C + NBC and between 35°C and 35°C + NBC. This analysis was chosen to focus on the impact of thermal strain on cognition.

6. Results

6.1 Heart Rate and Core Temperature

The heart rate (HR) and deep core temperature are critical physiological variables indicative of the level of thermal strain of the subjects (Fig 3). A one-way repeated measures of ANOVA indicated that there were significant differences in the mean HR between treatments measured across the recording period ($F(2,20) = 237.6$, $p<0.0001$). Subsequent analysis by Newman-Keuls post-hoc comparisons showed significant differences between the mean HR recorded in the thermally stressful (35°C, $p=0.009$) or thermally straining (35°C+NBC, $p=0.0002$) conditions and the thermally neutral condition (25°C). There was also significant difference in the mean HR between the thermally stressful and thermally straining conditions ($p=0.0002$).

Similar trends were observed for the mean core temperature. Significant differences were observed between treatment sessions ($F(2,20) = 139.8$, $p<0.0001$). Post-hoc comparisons also revealed the difference in mean core temperature recorded under 25°C or 35°C and 35°C+NBC ($p=0.00015$).

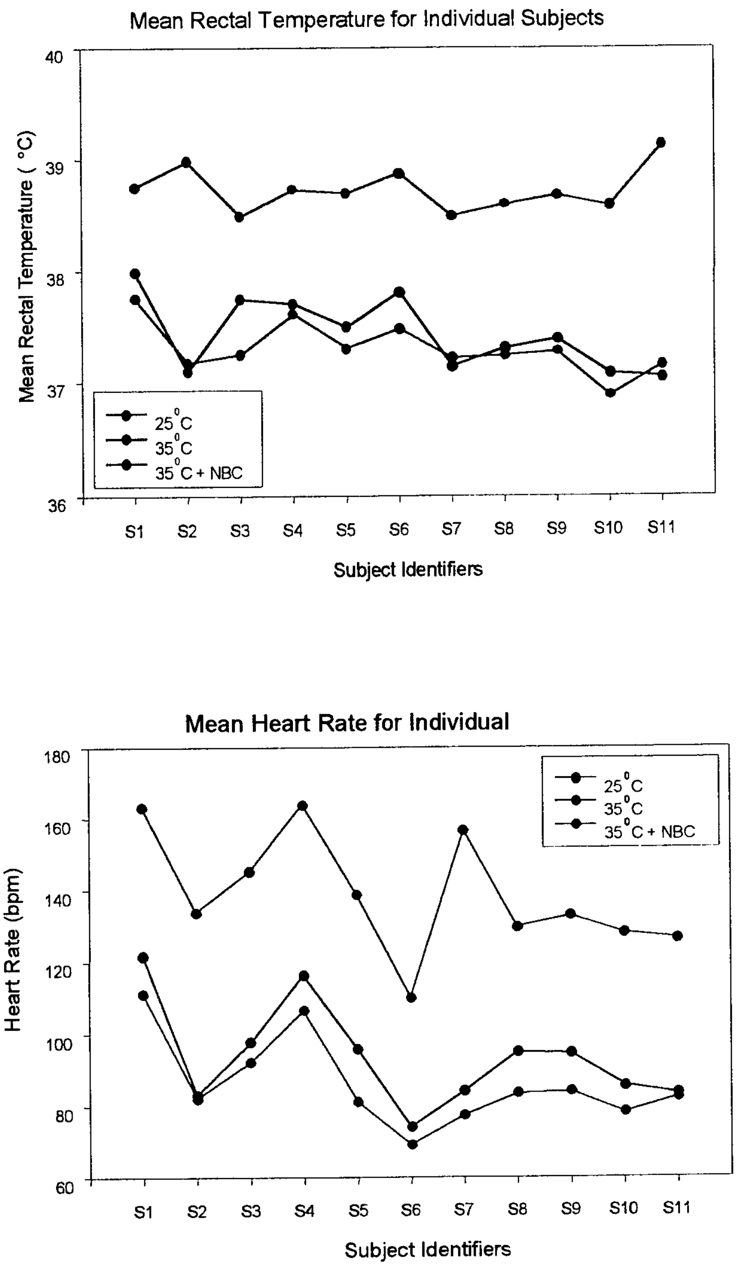


Figure 3: *Mean heart rate (b.min^{-1}) and core temperature (℃) during each recording session for each subject. Sustained elevation of both heart rate and core temperature is evident for the 35 ℃+NBC condition.*

Table 2: Mean values of heart rate and rectal temperature during recording sessions

Condition	Mean Heart Rate ($b.min^{-1}$)	Mean Core Temperature (°C)
25°C	86 ± 13	37.3 ± 0.2
35°C	94 ± 14	37.4 ± 0.3
35°C+NBC	139 ± 17	38.7 ± 0.2

Table 2 shows the mean heart rate and rectal temperature results. Statistical analysis indicates that both the core temperature and HR were significantly elevated during the 35°C+NBC trial compared to the thermally neutral (25°C) and the thermally stressful (35°C) conditions. The mean core temperature was approximately maintained at the specific threshold of 38.5°C when subjects were thermally strained (35°C + NBC). Increasing the thermal strain through increase in ambient temperature alone or together with physical exertion resulted in progressive increase in cardiovascular strain. A rise of 10°C in environmental temperature (from 25°C to 35°C) contributed to a rise of mean HR of 8 $b.min^{-1}$. This was increased by 53 $b.min^{-1}$ when subjects exercised in 35°C heat with NBC protective suit. These findings are concomitant with the ISO specifications (1992). At an average age of 31, the cardiovascular strain on the subjects was high during the 35°C+NBC trial as the mean HR reached 73% of the estimated maximum. It is evident that the combination of thermal stress and physical exertion in this trial was substantial.

6.2 Psychometric Task Performance

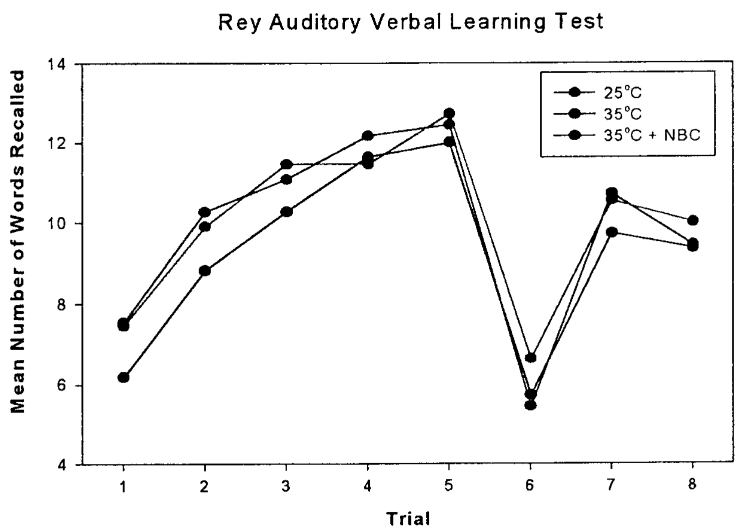
The relevant behavioural data (accuracy) for each test was analysed using a within subjects design repeated measures analysis of variance (ANOVA). For the psychometric tasks (RAVLT, Digit Span and Inspection Time), three measures showed significant differences across the treatment conditions.

For the Rey Auditory Verbal Learning Test, a learning curve across Trials 1-5 is evident (Figure 4), as is the reduced ability to recall a second list of words (Trial 6). There appears to be little difference in number of words recalled between Trial 7 and Trial 8 (Delayed Recall).

Trial 2 of the RAVLT showed a significant difference across the three conditions ($F(2,9) = 6.09$, $p=0.021$), but simple contrasts (which compare each of the thermal conditions to each other and indicate which differences were significant) showed that the 35°C condition was significantly different from both the 25°C condition ($F(1,10)=5.714$, $p=.038$) and the 35°C+NBC condition ($F(1,10)=8.101$, $p=.017$). Despite this observation,

all other trials showed similar performance ($p>0.05$) in each condition suggesting that there was no effect of thermal strain.

Digit Span Forwards results indicate little difference between the three conditions, but a deterioration in performance with raised core temperature showed a trend towards significance for Digit Span Backwards (see Figure 4).



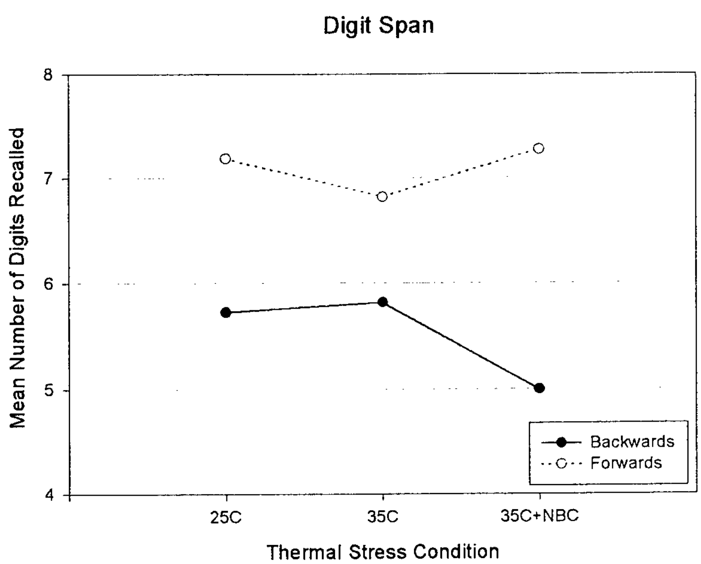


Figure 4: Performance on the RAVLT and Digit Span for the three thermal stress conditions.

Digit Span Backwards results showed a trend towards significance (F(2,9) =4.262, p=.05) and the contrasts revealed that performance in the raised core temperature condition (35°C+NBC) was significantly lower than in the 25°C (F(1,10)=7.11, p=.024) and 35°C (F(1,10)=5.400, p=.042) conditions, suggesting that there may have been an effect of thermal strain.

Inspection Time was also significantly different across the three conditions (F(2,9)=9.387, p=.006). The contrasts revealed a significant difference of both the 35°C (F(1,10)=19.582, p=.001) and 35°C+NBC (F(1,10)=6.539, p=.029) conditions from the 25°C condition (see Figure 5). There was no difference in performance under both the 35°C and 35°C+NBC conditions (F(1,10)=.137, p=.719) suggesting that an increase in ambient temperature alone may be sufficient to cause a deficit.

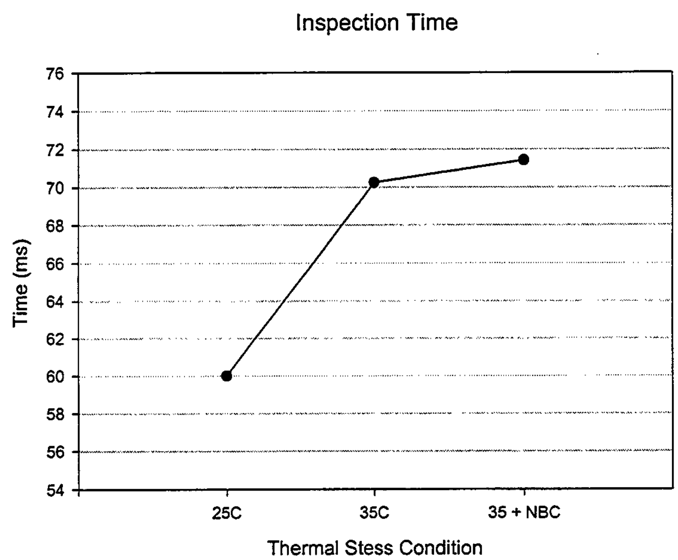
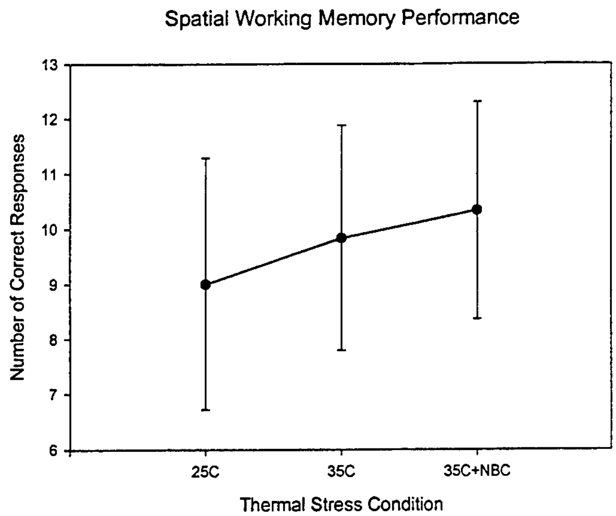


Figure 5: Inspection Time performance across the three thermal stress conditions. Inspection Time appeared to increase with increased ambient temperature.

Performance on the SSPT activation tasks (Spatial Working Memory and AX-CPT - see Figure 6) was based on accuracy and showed no significant difference across the thermal stress conditions for the whole group (n=11), nor for the 6 subjects whose SSPT data was averaged to provide the brain electrical activity results presented in the next section (AX-CPT - F(2,4)=2.092, p=0.174; Spatial Working Memory - F(2,4)=0.932, p=0.426). Exclusion of data for five subjects for SSPT computation was due to the inferior quality of the electrophysiological data recorded in at least one of the experimental conditions. The small number of samples also restricts the statistical power of the analysis.



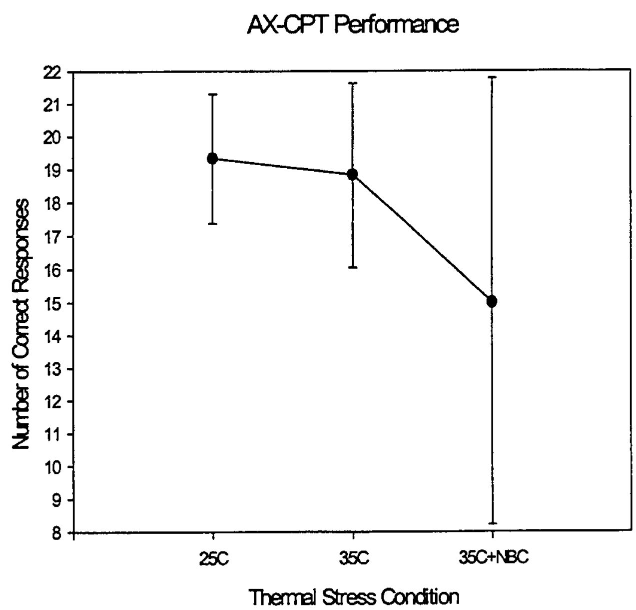


Figure 6: *Performance on SSPT Activation Tasks during the three thermal stress conditions. The apparent decrement in performance for the AX-CPT during the raised core temperature condition was not significant*

6.3 Brain Electrical Activity at Single Electrodes

6.3.1 Spatial Working Memory Task

In the spatial working memory task, comparisons of the SSVEP data across conditions was restricted to the interval in which subjects were required to hold the information in working memory. For the raised core temperature condition, frontal regions showed sustained increased SSVEP amplitude and decreased latency during the retention interval or 'holding period'.

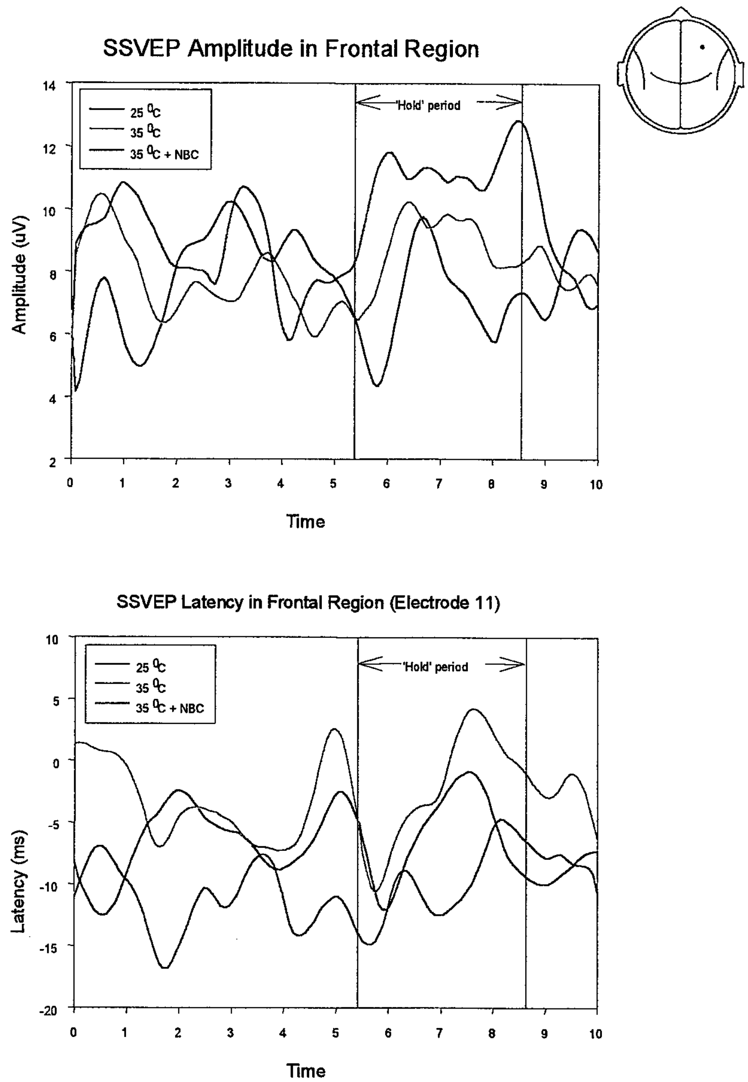


Figure 7: SSVEP amplitude and latency during performance of the Spatial Working Memory task during the three thermal stress conditions. Brain activity at electrode 11 was representative of activity across the frontal brain regions, which have been shown to be involved in working memory. The raised core temperature condition showed increased amplitude and decreased latency compared to the 25 °C and 35 °C conditions.

6.3.2 AX-Continuous Performance Task

For the increased core temperature condition, at occipito-parietal sites, the presentation of the 'A' and the 'X' was associated with a transient increase in SSVEP amplitude and transient decrease in latency.

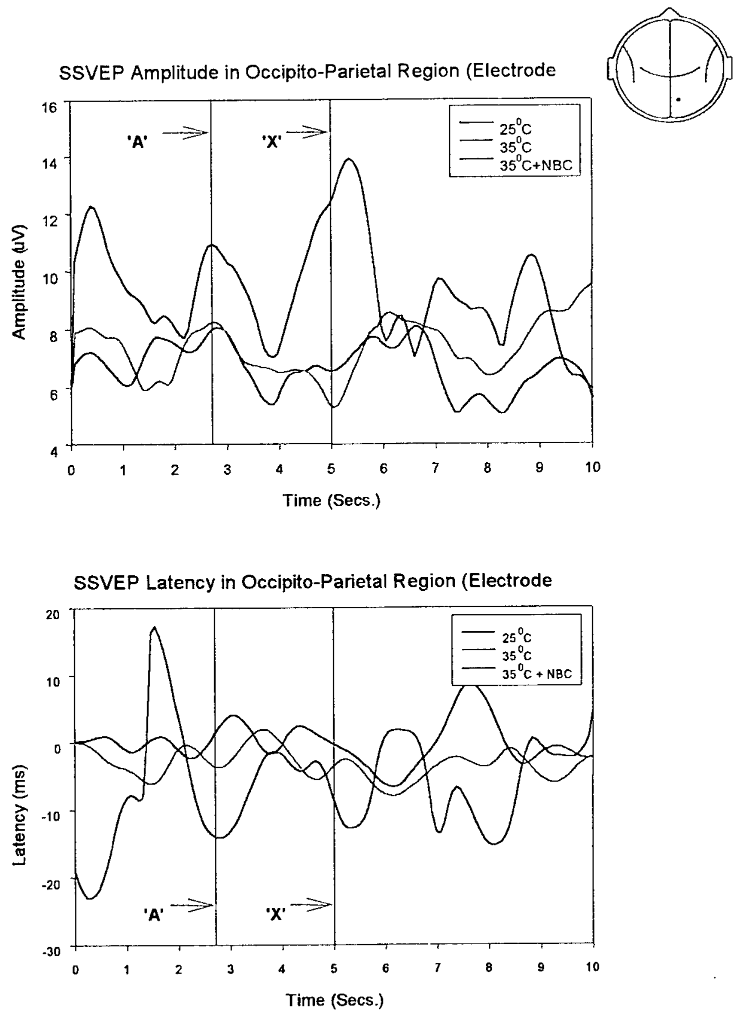


Figure 8: *SSVEP amplitude and latency during performance of the AX-Continuous Performance Task during the three thermal stress conditions. Brain activity at electrode 56 was characteristic of activity in occipito-parietal regions that are thought to be important in vigilance. During the raised core temperature condition, subjects showed increased amplitude and decreased latency compared to the other two conditions.*

6.4 Brain Electrical Activity Topographic Maps

These maps are based on a subtraction methodology, whereby amplitude and latency data from one condition (i.e., 25°C condition) were subtracted from another condition (in this case, the 35°C + NBC condition). This process cancels out common task effects, leaving maps which reflect differences between the two thermal stress conditions of interest.

6.4.1 Spatial Working Memory Task

The SSVEP topographic maps reveal that in the frontal regions, which have been shown to be involved in working memory, amplitude is increased and latency decreased for the raised core temperature condition compared to the other two thermal stress conditions.

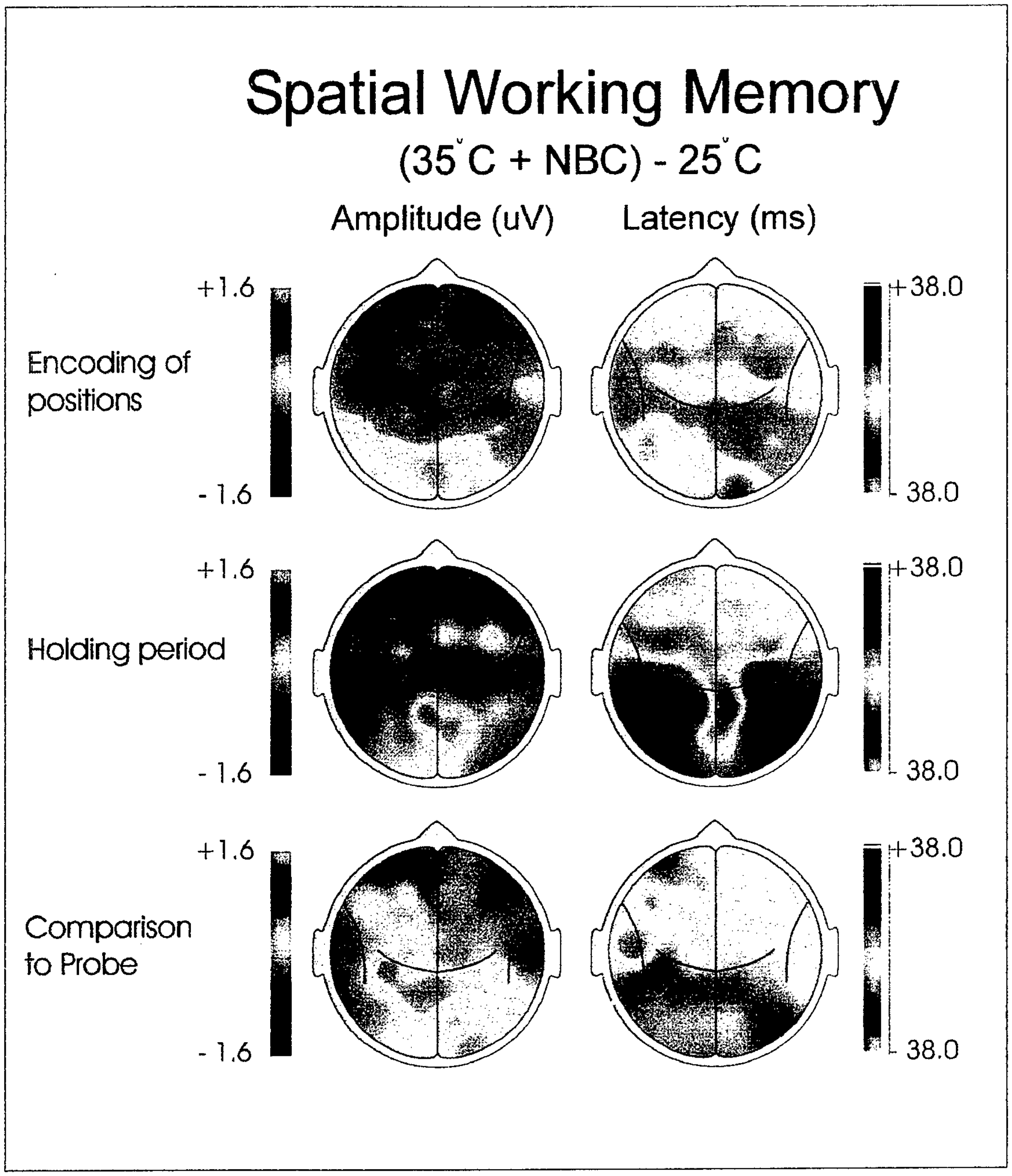


Figure 9: Topographic maps showing the differences in SSVEP amplitude and latency between the 25°C and raised core temperature (35°C+NBC) conditions during performance of the Spatial Working Memory task. During the 'holding period', when spatial information was retained by the subject, amplitude was increased and latency decreased in the raised core temperature condition compared to the 25°C condition.

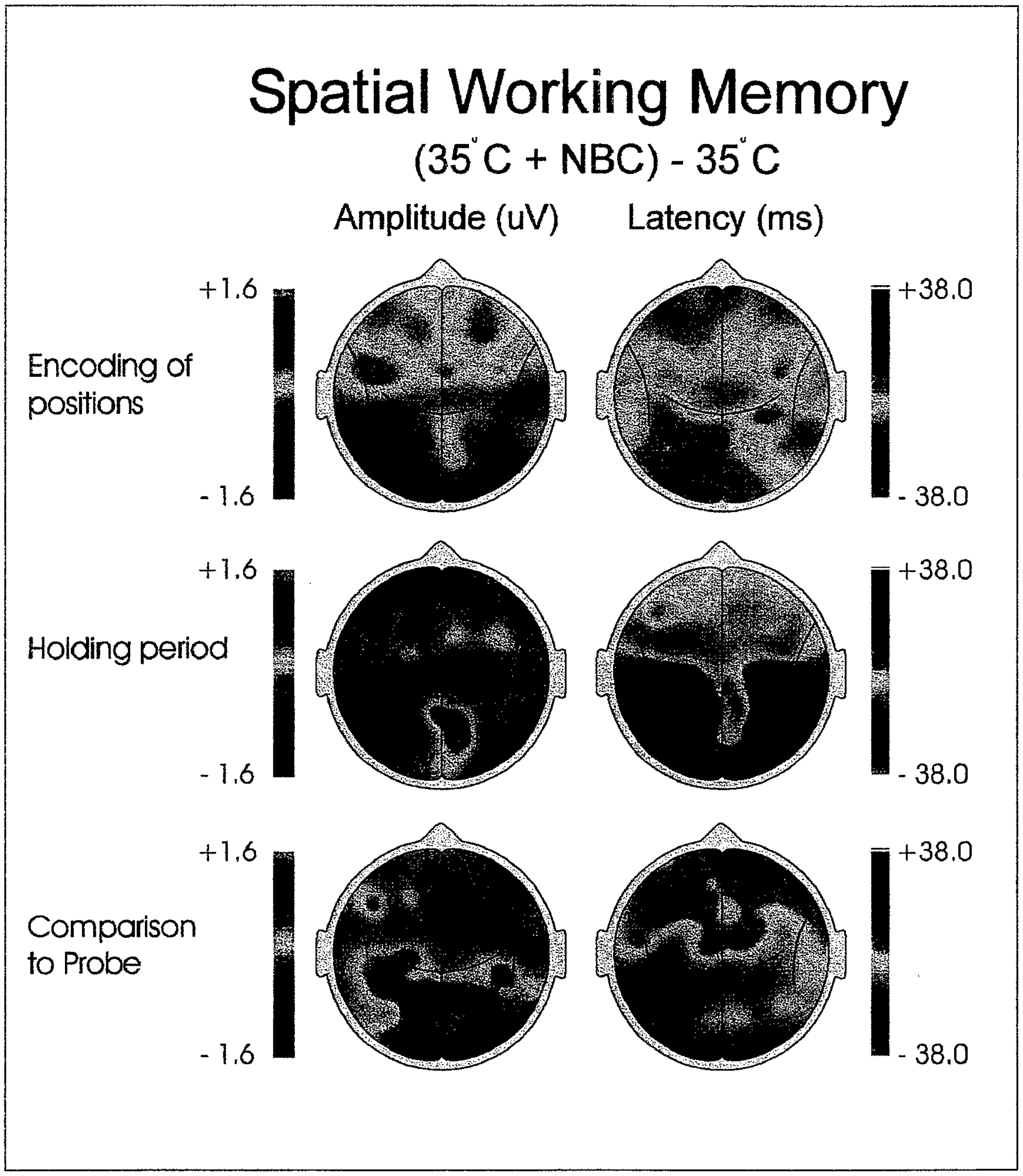


Figure 10: Topographic maps showing the differences in SSVEP amplitude and latency between the 35°C and raised core temperature (35°C+NBC) conditions during performance of the Spatial Working Memory task. The raised core temperature condition showed increased amplitude and decreased latency compared to the 35°C condition.

6.4.2 AX-Continuous performance Task

These topographic maps show that detection of the target 'X' was associated with increased amplitude and decreased latency in occipito-parietal regions for the raised core temperature condition compared to the 25°C and 35°C conditions.

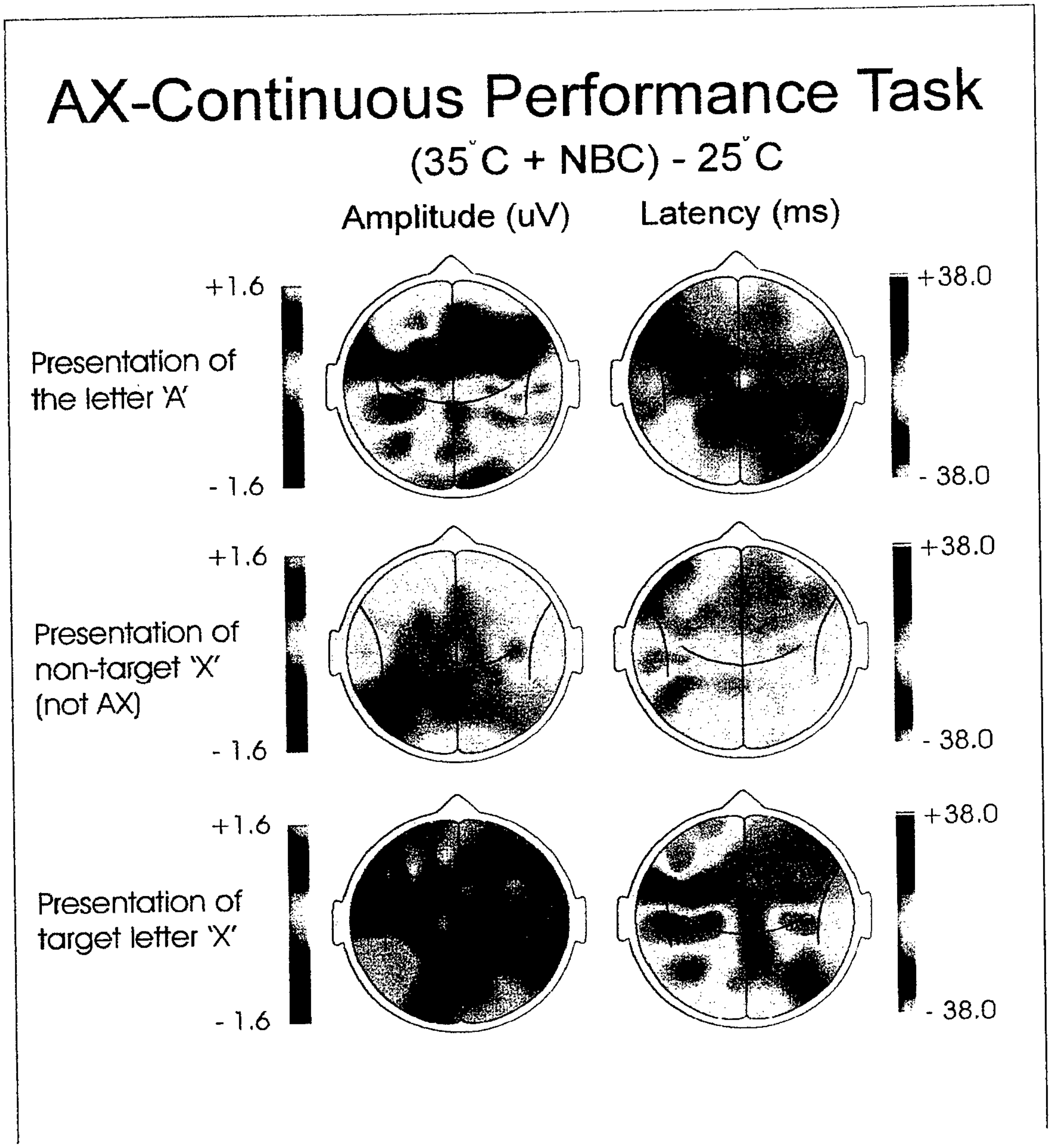


Figure 11: Topographic maps showing the differences in SSVEP amplitude and latency between the 25°C and raised core temperature (35°C+NBC) conditions during performance of the AX-Continuous Performance Task. During the raised core temperature condition, subjects showed increased amplitude and decreased latency (relative to the 25°C condition) in occipito-parietal regions that are thought to be important in vigilance.

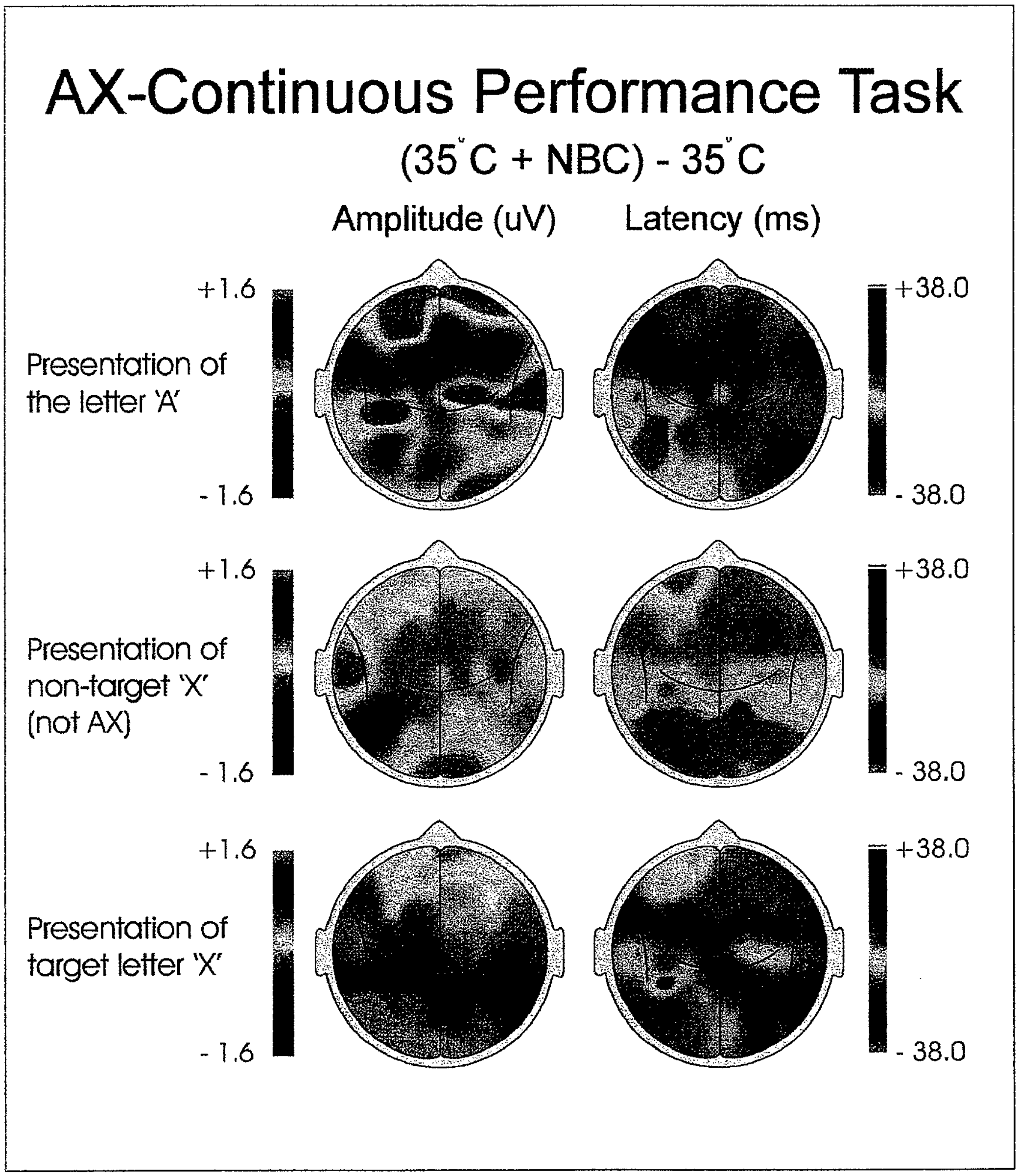


Figure 12: Topographic maps showing the differences in SSVEP amplitude and latency between the 25°C and raised core temperature (35°C+NBC) conditions during performance of the AX-Continuous Performance Task. Relative to the 35°C condition, subjects showed increased amplitude and decreased latency during the raised core temperature condition.

7. Discussion

The Results section showed that two psychometric measures (RAVLT and IT) revealed significant changes in performance across the three temperature conditions. The pattern of these results suggest that they were not due to increased core temperature or thermal strain, although there does appear to be a possible effect of ambient temperature on Inspection Time. This may be associated with the proposed up and down-regulation of arousal by environmental heat stress when subjects were performing vigilance task (Allan and Gibson, 1979; Hancock, 1986). For Digit Span Backwards, there appeared to be a performance decrement due to increased core body temperature and thermal strain, but this result revealed only a trend towards significance.

The fact that there were no significant decrements in performance of most of the psychometric tasks with increased core temperature would seem to suggest that thermal strain had little or no effect on the ability of subjects to perform the tasks. However, the decrement for Inspection Time during the high ambient temperature (35°C and 35°C + NBC) conditions was a promising result. Inspection Time is widely regarded as indexing the efficiency of the encoding stage of visual information processing and therefore reflects an early stage of information processing most basic to cognition (Deary & Stough, 1996). Biological studies have examined neurotransmitter hypotheses of IT performance and have generally concluded that IT performance is strongly influenced by cholinergic neurotransmission (Deary and Stough, 1996; Thompson et al, 2000). The results of the present study indicate that a rise in ambient temperature rather than thermal strain could have altered cholinergic neurotransmission under the present experimental protocol. This finding is important because IT has been strongly linked to intelligence and cognitive performance (Nettelbeck, 1987; Kranzler & Jensen, 1989) and appears to play a central role in providing the central executive with basic information to enact decisions. Along these lines it has been suggested that IT performance is basic to complex decision making and that disruption to the encoding of information at the early stages of information processing on a long term basis may lead to abnormal cognitive processes. The trend towards a significant difference observed for Digit Span Backwards was also interesting but the results were achieved with a very small subject pool (n=11). Overall, these observations warrant further investigation, given that it is conceivable that this change may be significant for a larger sample of subjects.

A review of literature on the effects of thermal stress on sustained attention by Hancock (1986) suggests that hyperthermia can improve performance, but only if the increase in temperature does not disturb homeostasis (i.e., the hyperthermic state of the subject is static). These conditions are similar to those observed during the sequential increase in temperature associated with the circadian rhythm. Under these circumstances, in which the relative rate of change of body temperature is small, performance improves with ascending temperature level (Kleitman, 1963). However,

Hancock (1986) further suggested that exposures to thermal stress that perturb deep body temperature away from both normal and steady-state conditions could impair vigilance. In addition, stress acts to drain attentional resources and thereby leaving less attentional resources left to perform a task.

Given that the thermal stress experienced by the subjects did in fact perturb their core body temperature away from homeostasis, this then raises the question of why we did not see any decrements in performance of the psychometric tasks. A possible answer to this question becomes apparent when we consider the SSVEP data.

Regarding the SSPT results, the main finding from this study was that compared to the 25°C and 35°C conditions, the raised core temperature (35°C + NBC) condition showed increased SSVEP amplitude and decreased latency, notably in frontal regions for the Spatial Working Memory task, and in occipito-parietal regions for the vigilance task (AX-CPT). It is suggested that these changes during the raised core temperature condition were reflective of increased brain activity associated with performance of the tasks. Perhaps more interesting still was the fact that while there were marked changes in the SSVEP, the performance on the SSPT activation tasks was not significantly different across the three temperature conditions. This result suggests that there were changes in the underlying brain activity supporting task performance that were not reflected in changes in the level of task performance.

A perturbation of thermal homeostasis and an increase in brain activity during task performance under the thermally strained condition suggests that the greater brain activity indicated by the SSVEP results reflects a greater utilisation of neural resources or effort by subjects to maintain performance at the same level as when they were not thermally stressed. This finding is consistent with those of a previous study by Silberstein et al (1996), which showed that compared to trials of the AX-CPT, which were responded to slowly, trials which were responded to fastest and presumably requiring more effort, showed reduced latency in prefrontal regions. Decreased latency in frontal regions has also been found in a graded Spatial Working Memory task. Similarly to the Spatial Working Memory task used in this study, subjects were required to remember the locations of two or four objects and compare them to a probe item. Remembering four locations was more difficult than remembering two, and the SSVEP results reflected this, showing a graded effect for latency, with the four-location condition showing decreased latency compared to the two-location condition (Silberstein et al., 1999).

This interpretation is suggestive of the existence of a 'cognitive reserve', whereby subjects have at their disposal a certain amount of neural resources that can be allocated to the performance of tasks and activities. All cognitive processes increased activity in specific networks of neurons distributed over the brain. The 'cognitive effort' will be a function of both the number of neurons that are recruited to the task and the increased firing frequency of those cells. Low demand tasks may only recruit a small proportion of the total pool while a higher demand task may recruit a much

higher proportion. If the maximum number of elements that can be physiologically recruited in the cognitive task is 100% then the reserve is the difference between what is recruited and 100% (Wickens, 1984; Hart and Wickens, 1990).

Our finding that thermal stress led to a larger SSVEP signal associated with the working memory task. This suggests that more neurons were recruited in the thermal stress condition and the reserve is thus reduced. Performance of these tasks and activities will deteriorate when the amount of resources is insufficient to deal with both the tasks and thermal stress, such that subjects will be able to maintain their performance level until the resources are overloaded. Such a construct is consistent with attentional resource capacity explanations of the effects of thermal stress on vigilance (Hancock, 1986), in which stress is viewed as draining attentional resources. In the case of this study, whilst task performance was not affected by thermal stress, the SSPT results suggest that this was achieved by the use of more attentional resources or effort by subjects to compensate for the 'draining' effect of thermal strain. Hart and Wickens (1990) argued that primary task measures such as reaction time, tracking tasks and target acquisition will have little relevance to identify one's reserve capacity when asked to perform for prolonged period or under difficult environments. This contention falls in line with our findings which showed little behavioural change when subjects were thermally strained. It was suggested that concurrent and additional tasks of secondary nature are better measures to index the reserve capacity.

These findings indicate that brain imaging methodologies can make a valuable contribution to the field of human factors in providing empirical measurement that complements and goes beyond measures of behavioural responses.

However, caution must be exercised in the interpretation of these results. Although the level of thermal stress applied in this study is substantial, the impact of thermal strain on individual is largely unclear. This is due to the fact that the elevation of core temperature and heart rate could be influenced by confounding factors such as the fitness and hydration status, the physical and mental conditions of the subjects prior to the trial as well as their general health condition. The outcomes of the SSVEP recording and the behavioural responses could be a reflection of the collective influence of these factors rather than thermal strain alone.

8. Conclusion

This study examined the validity of a brain imaging technique and some conventional psychometric tests for the assessment of the impact of thermal strain on cognition. The study was conducted using only a small sample of volunteers (n=11). Furthermore, the subjects were all civilians and as a result, their core temperature had only been raised to a level that is much lower than the normal level a soldier would experience in

training or routine operations. In addition, the physical fitness and the physiological status of the volunteers pre- and post-trial were not determined due to a concern over their ability to complete the test. It is therefore prudent to use the results as general guidance rather than to draw definitive conclusions on the impact of thermal strain on cognition. Based on the outcomes of the study, the following points are noted:

1. Subjects experienced substantial cardiovascular strain as a result of the high environmental stress. A higher level of heat strain (mean core temperature of >38.5°C) was maintained when subjects wore an NBC suit and exercised in the heat.

2. Two psychometric measures, the RAVLT and IT, showed significant changes across the three experimental conditions, although the changes could not be directly linked to the increase in thermal strain.

3. A performance decrement was recorded in the Digit Span (backward) test under thermally straining condition (35°C + NBC). Nevertheless, the impact of thermal strain on information retention revealed only a trend towards significance.

4. In general there are no significant behavioural changes due to higher thermal strain.

5. Brain electrical activities measured by SSVEP indicated an increase in amplitude and a decrease in latency in the frontal and occipito-parietal regions under thermally straining conditions (35°C +NBC).

6. The changes of the SSVEP are not reflected by corresponding decrements in performance of the SSPT activation tasks across the three experimental conditions.

7. The outcomes suggested that the recorded increase in brain activities across the three conditions is an indication of greater utilisation of the neural resources to maintain behaviour and/or performance.

8. It was proposed that there is an increase in the recruitment of neural resources to compensate for increasing demand in performance due to external stress. However, when this reserve is overloaded, behavioural changes or performance decrements will become more evident.

The results of this study indicate that the SSVEP and SSPT methodologies are highly sensitive techniques suitable for the determination of the empirical relationships between the electrical responses of the brain and external stimulus. Subtle changes in brain electrical activities can be detected and differentiated that go beyond the measures of behavioural changes. It is recommended that application of brain imaging techniques for the evaluation of cognitive performance in military scenarios should be further investigated, preferably with soldiers volunteering for the studies.

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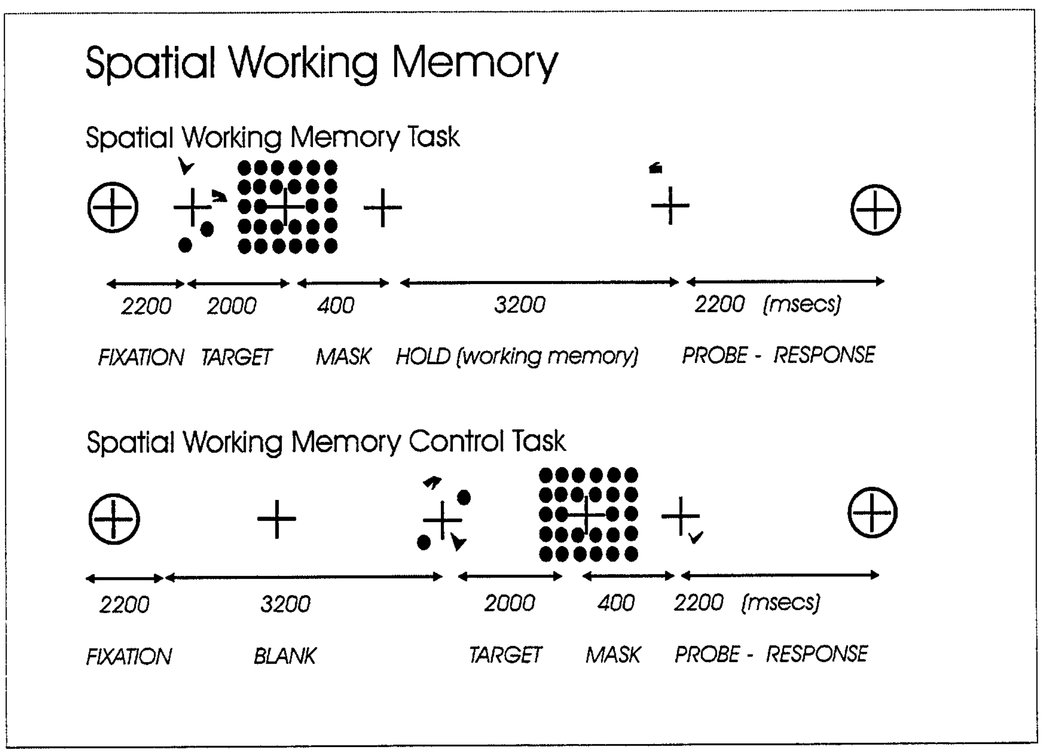
Appendix A: Computer-based Psychometric Tasks

Cognitive activation tasks were selected to enable SSPT investigations of spatial working memory and vigilance.

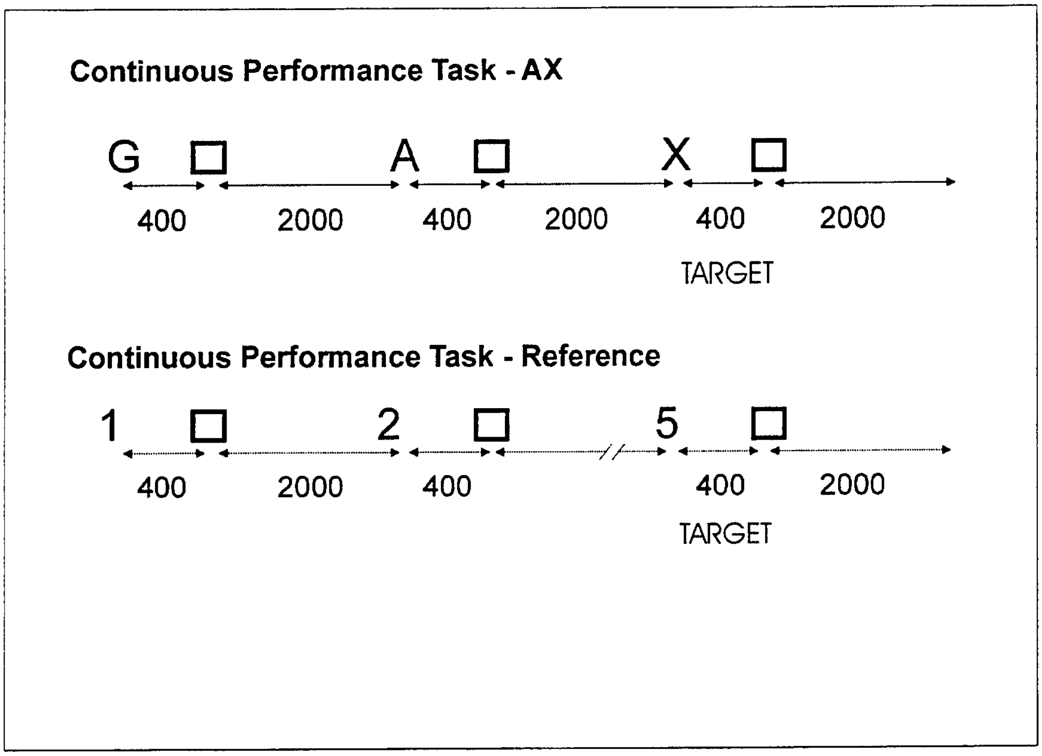
A.1. Spatial Working Memory

A delayed match-to-sample task paradigm was used for Spatial Working Memory activation. A series of 'test' stimuli comprising two polygons and two circles were presented on a computer monitor for 2200ms, which was then replaced by a mask which covered all locations, and followed by a fixation cross which was displayed for 3200ms. The task of the subjects was to remember the location on the screen of the 2 polygons during this time ('retention interval'). The retention interval was followed by a 'probe' stimulus comprising a single polygon, and subjects had to indicate whether the probe matched the spatial location of any one of the two original 'target' polygons. The design of the Spatial Working Memory task was closely modelled on the description outlined by Smith et al. (1995). The maximum score for this task is 13 spatial matches.



A.2. Vigilance

Subjects undertook a low- and high-demand version of the Continuous Performance Task (CPT). In the low-demand version, subjects were required to press a micro-switch on the predictable appearance of a number (5) presented on a computer monitor (CPT-Reference). In the high-demand version, subjects pressed the micro-switch on the unpredictable appearance of the letter 'X' only when it had been preceded by the letter 'A' (CPT-AX). Maximum score that one can achieve in this task is 26 correct responses.



A.3. Inspection Time

Presentation of "*pi figure*" *(horizontal bar with two vertical lines of unequal length)* followed by a backward masking stimulus.

Stimulus duration typically 200ms to <10ms.

Subject indicates whether <u>shorter</u> vertical line occurred on left or right side of figure.

A.4. Instructions for Psychometric Tasks

A.4.1 Auditory Verbal Learning Test (AVLT)

- This test consists of 5 presentations with recall of a list of 15 words (Trials 1 – 5: List A).
- A second list (List B) is presented in the 6th trial with recall of that list. Trial 7 is a recall of List A.
- 30 Minutes later recall of List A is requested again.
- If the subject recalls less than 13 of the words in List A they are required to do Trial 9: Recognition.

Trial 1:

"I am going to read a list of words. Listen carefully, for when I stop you are to say back as many words as you can remember. It doesn't matter what order you repeat them in. Just try to remember as many as you can."

Trials 2-5:

"Now I'm going to read the same list again, and once again when I stop I want you to tell me as many words as you can remember, including words you said the first time. It doesn't matter what order you say them in. Just say as many words as you can remember, whether or not you said them before."

Trial 6:

"Now I'm going to read a second list of words. This time you are to say back as many words from this second list as you can remember. Again, the order in which you say the words does not matter. Just try to remember as many as you can."

Trial 7:

"Now I would like you to recall as many words as you can from the first list."

NB: If the test is to be administered more then once, use the alternate forms that are available - 1,2,3, and 4.

A.4.2 Digit Span

Forward:

"I want to see how well you can pay attention. I am going to say some numbers and when I am finished I want you to say them right after me. Listen carefully. If I say 3-9-5, you say (get subject to respond)".

Backward:

"Now I am going to say some more numbers, but this time when I stop I want you to say them backwards. So if I say 1-7, what would you say? (get subject to respond)".

A.4.3 Inspection Time

"You will be presented with a figure which is made up of a horizontal bar with two vertical lines of unequal length. This figure will be presented on the screen for a very short period of time and will then be replaced by a mask that will hide the original figure. Your job is to indicate whether the shorter line is on the left or right side of the figure, using the 'Z' and "?" keys respectively.

Appendix B: Statistical Results

B.1. RAVLT Trial 2

F(2,9) =6.09, p=.021

Simple Contrasts	25C and 35C (F(1,10)=5.714, p=.038)
	35C and 35C+NBC (F(1,10)=8.101, p=.017)
	25C and 35C+NBC (F(1,10)=.288, p=.603)

B.2. Digit Span Backwards

F(2,9) =4.262, p=.05

Simple Contrasts	25C and 35C (F(1,10)=.061, p=.810)
	35C and 35C+NBC (F(1,10)=5.400, p=.042)
	25C and 35C+NBC (F(1,10)=7.11, p=..024)

B.3. Inspection Time

F(2,9) =9.387, p=.006

Simple Contrasts	25C and 35C (F(1,10)=19.582, p=.001)
	35C and 35C+NBC (F(1,10)=.137, p=.719)
	25C and 35C+NBC (F(1,10)=6.539, p=.029)

B.4. AX-CPT

F(2,4)=2.092, p=0.174

Simple Contrasts	
25 vs 35	F(1,4)= 0.429, p=0.542
35 vs 35NBC	F(1,5)= 1.926, p= 0.224
25 vs 35NBC	F(1,5)= 2.374, p= 0.184

B.5. Spatial Working Memory

F(2,4)=0.932, p=0.426

Simple Contrasts	
25 vs 35	F(1,4)= 0.598, p=0.474
35 vs 35NBC	F(1,5)= 0.273, p= 0.624
25 vs 35NBC	F(1,5)= 2.105, p= 0.206

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TheEffects of Thermal Strain on Cognition

Chris Hocking, Wai Man Lau, Richard Silberstein, Warren Roberts
and Con Stough

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19. ABSTRACT

Military operations in tropical environments have imposed a significant challenge to the Australian Defence Force (ADF). The hot and humid conditions are known to cause debilitating effects on soldiers deployed to northern regions of Australia, with the consequence that the effectiveness and efficiency of operations were severely compromised. While the adverse effects of thermal stress on soldiers' physiological capability are well established, this has not been confirmed for cognitive performance. This impact of thermal strain on cognition has now been studied using psychometric testing and functional brain electrical activity imaging to investigate the impact of thermal stress on cognitive performance. The brain electrical activity of subjects was measured while undertaking a range of cognitive tasks. Steady State Probe Topography (SSPT), a novel brain imaging technology, was employed to monitor the changes in regional brain activity and neural processing speed of subjects under thermal stress. The psychometric test batteries, developed by the Brain Sciences Institute (BSI), were made up of the Rey auditory-verbal learning test, the inspection time, the digit span test the spatial working memory task and the AX-continuous performance task

The functional brain imaging provides topographical information, which shows changes of electrical activity in response to thermal stress during cognitive task performance. The changes in brain electrical activity and neural speed induced by thermal stress will help to identify the type of cognitive functions that are likely to be impaired.

Results indicated that subjects experienced increasing cardiovascular strain through thermally neutral to thermally straining conditions. The heat strain imposed on the subjects was substantial as indicated by the increase in their mean core temperature under thermally straining conditions. The psychometric test batteries, however, showed no significant performance decrements even under the most strenuous condition. Some deficits in working memory, in information retention and processing were noted but overall, behavioural changes that were reflective of the higher level of thermal strain were not observed.

In contrast, there were marked differences in the electrical responses of the brain when subjects were thermally strained. The Steady State Visual Evoked Potential (SSVEP) recordings showed an increase in amplitude and a decrease in latency, suggesting an increase in the utilisation of neural resources or effort by subjects to maintain the same level of performance under thermally neutral conditions. It appears that the brain imaging technology is potentially a valuable tool for examining the empirical relationships that complements and goes beyond conventional measures of behavioural responses.